Construction and Building Materials 174 (2018) 520–528

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Quantitative study on strength development of earth-based construction prepared by organic clay and high-efficiency soil stabilizer

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HIGHLIGHTS

- The earth-based construction is prepared by organic soil and high-efficiency stabilizer.
- The strength-calculation model is proposed, and its deviation is lower than 10%.
- The possible mechanism for effects of fly ash and organic matter is explained.

ARTICLE INFO

Article history:
Received 21 February 2018
Received in revised form 12 April 2018
Accepted 13 April 2018

Keywords:
Earth-based construction
Compressive strength
Reconstituted organic soil technique
Pozzolanic and dispersing effects
Strength-calculation model

ABSTRACT

The earth-based construction with unique advantages in raw material origin, energy conservation and environment protection has attracted growing attention recently. In South China, raw soils which have been used for hundreds of years are mainly organic clays with high water and organic matter contents. This research uses reconstituted organic soil technique for preparing earth-based construction in order to analyze effects of fly ash and organic matter on compressive strength quantitatively. The used cementing material is a high-efficiency stabilizer called CSCN, and organic clay is obtained by mixing humic acid powder (HAP) with raw soil. Compressive strength is measured to investigate the influence of fly ash, and XRD and SEM analysis are used to understand the mechanism of fly ash in stabilized earth with HAP. The hypothetical CSCN content of fly ash and CSCN-consumption content of HAP are proposed by redefining the P&D factors (k_{fh}) and consumption index (OCI_{fh}). Subsequently, the strength-calculation models are proposed, and the deviation between the calculated strength and measured strength is not more than 10%. The changes in the quantity and type of hydration products observed from XRD patterns and SEM photos may explain the mechanism of fly ash in earth-based construction with organic matter.
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1. Introduction

During the last decade, sustainable development has attached importance because of the environmental pollution and climate change [1]. And it is commonly believed that the construction and operation of modern buildings consume huge amounts of energy and emit massive greenhouse gas. Therefore, one of the traditional architectures, rammed earth construction whose base material is raw soil, has been reported and applied as an alternative and environmentally friendly method recently [2]. For improving the strength of earth-based structure, the usage of a small quantity of cementing materials is essential. Among the cementing materials, Portland cement and cement-based composites are commonly employed. Among the cementing materials, Portland cement and cement-based composites are commonly employed. Because the raw soil distributed in southeastern China has a high water content, and the earth-based construction can be obtained by only mixing and vibration processes without compaction energy [3].

Earth-based constructions such as earth towers of the Hakks prepared by soft marine clay has been used for a long time in Fujian province, South China. Although the raw materials of the Hakks are mainly organic clay and lime, the Hakks have survived hundreds of years which implies the excellent durability of earth-based construction. During the preparation process of earth-based constructions, the precipitation and compaction energy are necessary, which occupies huge areas of cultivated land and emit some unpleasant gases [4]. Therefore, earth-based construction without compaction process can be employed to replace conventional rammed earth. Indeed, many raw soils in South China are organic clays. Although the organic matter content in most

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https://doi.org/10.1016/j.conbuildmat.2018.04.119
0950-0618/© 2018 Published by Elsevier Ltd.

Notation

The following symbols and abbreviations are used in this paper:

C	defined total CSCN content in theory
C_{CS}	actual CSCN content
C_e	summation of equivalent CSCN of fly ash and CSCN-consumption of HAP
C_{eF}	equivalent CSCN content of fly ash
C_{eH}	CSCN-consumption content of HAP
C_{FA}	actual fly ash content
C_{HAP}	actual HAP content
CSCN	a type of high-efficiency clay stabilizer
FA	fly ash
HAP	humic acid powder
k_{fh}	P&D factors of fly ash
OCI_{fh}	consumption index of HAP
P&D	pozzolanic and dispersing
q_u	unconfined compressive strength
SIF	strength improvement per one percent of fly ash
t	curing time
w_c	water content

soils varies from 0.2% to 7.5%, constructions prepared by organic clays are characterized by high compressibility and low strength which is too low to meet the strength-requirement of construction, and the common solution is to increase cement content which leads to cost increase and environmental pollution [5]. For this reason, some high-efficiency cement-based soil stabilizers including sodium silicate or other alkaline minerals were developed, and some industrial waste residues have been applied in practice [6–9]. Among the high-efficiency stabilizers, the cement-based composites named CSCN is an appropriate binder to prepare earth-based structures, and 12% CSCN can achieve the equivalent strength with about 20% cement [10–17]. On account of the high cost of admixtures in CSCN, fly ash was employed to replace the expensive materials and expand the application of CSCN.

Thermal power accounts for about sixty percent of total power supply in China, and massive fly ash can be collected in power plants. Although fly ash has been widely used in cement and concrete, most low-grade fly ashes are stacked in outdoor storage. As a type of commonly used waste residue, fly ash can reduce the construction cost significantly. Especially in recent years, the recycling of fly ash is becoming more important along with the proposal of strict environmental regulations in North and East China. The application of fly ash in geotechnical engineering and earth-based construction and its effects on mechanical properties on earth-binder mixture have been studied by many researchers [4,15,18–20].

Fly ash can improve the strength of rammed earth to some content, and its effect was quantitatively analyzed by defining clay-water/cement ratio and pozzolanic and dispersing factors [21,22]. It is reported that organic matter whose surface may adsorb hydrogen ion which performs neutralization reaction with hydroxide ion can affect cement hydration and pozzlanic reactions in organic soil-cement system, which indicates that pozzolanic and dispersing effects of fly ash may also change. In previous studies [16,23,24], the impacts of organic matter on properties of stabilized soil were semi-quantitatively and quantitatively analyzed by preparing reconstituted organic soils with different contents of humic acid. Therefore, the reconstituted organic soil technique may be a useful method to understand inter action among binder, soil, organic matter and fly ash. Nevertheless, there are very few studies on analyzing the effects of fly ash on strength development of stabilized earth with organic matter.

In this research, a type of soil stabilizer named CSCN which was developed in our previous study and reconstituted organic soil technique are employed. To study effects of fly ash on strength development of stabilized earth with organic matter, series of experiments were carried on specimens with different contents of binder, fly ash and huimic acid. Strength-improvement index is defined to confirm the interaction among base materials in earth-based construction. And the effect of fly ash is quantitatively analyzed by redefining its pozzolanic and dispersing effects through proposing hypothesis of clay-water/binder content ratio. Based on the above analysis, a strength-calculation model is proposed and its precision is also assessed. Finally, the mechanisms of fly ash in organic soil-binder system are investigated through XRD and SEM analysis.

2. Experimental approach

2.1. Materials

To simulate the actual organic soil and obtain accurate results, reconstituted organic soil technique is introduced for preparing earth-based construction. Reconstituted organic soil was obtained by mixing a projected content of humic acid into crushed original raw soil. The original soil was obtained from the Minghang Campus of SJTU in southwest Shanghai, and it is a marine clay. Its fine particle content is very high. The particle size analysis of raw soil is shown in Fig. 1. The oven-dried soil was crushed, and then sieved by a 2-mm sieve. The oxide composition of raw soil is presented in Table 1, and the microstructure and phase composition of raw soil characterized by SEM and XRD are illustrated in Fig. 2.

Humic acid powder (HAP) with pH value of 3.55 employed in this paper is black, and it is the generation of plants and animals which had been buried for thousands of years. The main composition elements of HAP are carbon, oxygen, nitrogen and hydrogen, and aromatic and cycloparaffinic rings are the fundamental structures. HAP has more than eighty-five percent of humic acid, and its main impurity is fulvic acid.

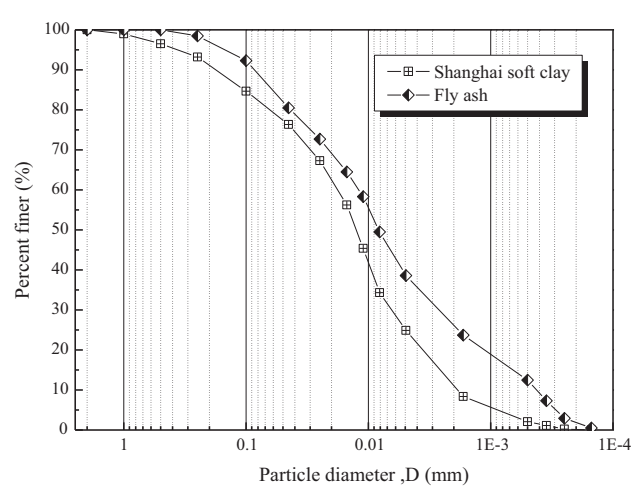

Fig. 1. Particle size distribution curves of raw soil and fly ash.

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